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ABSTRACT

To determine the relative importance of school and individual factors in the determination of science learning, achievement test scores were analyzed in relation to individual- and school-level factors in a national sample of about 2,000 tenth-grade students participating in the Longitudinal Study of American Youth. Hierarchical linear analyses showed that individual measures accounted for most of the variance. Previous achievement was the preponderant influence on subsequent achievement. Nonetheless, initial science attitude, instructional time, the home environment, and exposure to mass media were also significant individual-level influences on science achievement. (Author)

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# A Hierarchical Linear Model of Educational Productivity

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## ABSTRACT

*To determine the relative importance of school and individual factors in the determination of science learning, achievement test scores were analyzed in relation to individual- and school-level factors in a national sample of about 2,000 tenth-grade students participating in the Longitudinal Study of American Youth. Hierarchical linear analyses showed that individual measures accounted for most of the variance. Previous achievement was the preponderant influence on subsequent achievement. Nonetheless, initial science attitude, instructional time, the home environment, and exposure to mass media were also significant individual-level influences on science achievement.*

A theory of educational productivity (Walberg, 1981) holds that three groups of nine factors a) *aptitude* consisting of 1) ability or prior achievement, 2) motivation, and 3) age or developmental level; b) *instructional* 3) time and 4) quality; and c) the *psychological environments* of the 6) classroom, 7) home, 8) peer group, and 9) mass media are the major and consistent determinants of educational outcomes. The theory has guided the compilation of more than 120 research syntheses of 8,000 comparisons in small-scale experimental and correlational studies (Fraser, Walberg, Welch, & Hattie, 1987) and 23 regression analyses of achievement obtained from mostly national surveys of about 250,000 students in six subjects of primary and secondary school study (Paschal & Stariha, 1992). Although 303 (or 89%) of 341 regression weights were in the theoretically-predicted direction, much of data were cross-sectional; and the analyses made little use of structural modelling that takes into account indirect causation, reverse causality, measurement error, and lack of optimal scaling of variables.

To improve upon earlier estimates, Reynolds and Walberg (1991) employed the LISREL 7 program (Joreskog & Sorbom, 1988) which incorporates such structural modeling features. They tested the consistency of the findings with national longitudinal data on junior and senior high school students in mathematics and science over a one-year time span. When adjusted for the specification, measurement, and scaling errors in the data, the coefficients were generally higher than indicated by previous regression analyses and were generally in the expected direction. Therefore, it could be concluded that the model held up well under more rigorous tests than had been previously been made. This study, which included cross-validation, corroborated the mediating effects of the productivity factors not evident in previous studies.

However, one potential criticism of both regression and structural analyses is that they fail to take into consideration the multilevel nature of educational data which typically includes school, classroom and student levels (Burstein, 1980; Walberg, 1984; Bryk & Raudenbush, 1992). Psychologists can argue that educational factors are individual level measures and corresponding individual-level analyses should prevail in both experimental and correlational research. Statisticians and sociologists, on the other hand, point out that the teacher and students influence one another, and therefore their interdependence violates the statistical assumptions of the analysis and claims too many independent degrees of freedom, that is, corresponding to the number of students rather than the number of schools. An early and unsatisfactory solution for this problem is to carry out analyses at both individual and aggregate levels and look for robust findings across specifications (Walberg & Anderson, 1968).

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To answer such statistical criticism it has recently become possible to analyze multiple levels. For what has been termed "hierarchical linear modeling" analyses (HLM, Bryk & Raudenbush, 1992), several programs are now available that allow simultaneous analysis of two (and even three) levels. HLM programs employ a modified regression approach to estimate the multi-level coefficients and their significance. They also provide estimates of the variance accounted for by each level much like regression provides at a single level. Like regression, however, HLM lacks the special features of LISREL 7 such as multivariate coefficients in the case of multiple dependent variables and correction of attenuation attributable to measurement error and non-linear relations. Thus, it appears worthwhile subjecting well collected data sets to both structural and hierarchical tests for the magnitude and significance of effects.

## Methodology

### Sample Design

This study involved 2535 tenth-grade public school students and 51 schools that were a part of the Longitudinal Study of American Youth (LSAY; Miller, Suchner, Hoffer, & Brown, 1990). The sample design is two-stage stratified by region (East, West, North, and South) and by urbanity (rural, suburban, and urban). Missing data on science achievement and other variables reduced the sample sizes somewhat as indicated in a subsequent section.

Data collection for this study took place in the fall of 1987, spring of 1988, and fall of 1988. While students were tested for science achievement in the first collection in the fall of 1987 using NAEP tests (National Assessment of Educational Progress, 1986), attitudes towards science, motivation, peer environment, and weekly homework, the second collection in the spring of 1988 involved student and teacher surveys. In addition, parents were interviewed regarding student attendance, home resources, and exposure to mass media (television and books). Teachers provided information such as class environment and instructional quality. The third data collection in the fall of 1988 repeated the first collection of achievement and attitude data from the students. This study focused on the grade 10 cohort and the data collected while in grades 10 (1987) and 11 (1988).

### Analytic Method

The Longitudinal Study of American Youth dataset consisted of students residing in school and home. Although Reynolds and Walberg (1991, 1992) have reported results from the seventh and tenth grade cohort using structural modelling, the methodology for this investigation incorporated the hierarchical nature of students and schools in a procedure called hierarchical linear modelling. The nature of educational research about students residing in classrooms located within schools, within school districts, within states, etc. often fails to account adequately for the grouping attributes. The hierarchical order with each group influencing the members of the group in thought and behaviour can lead to problems with homogeneity of students within groups. If the school effects are ignored when comparing students, then the problem of biased significance tests will lead to erroneous results and inferences (Raudenbush & Bryk, 1986; Raudenbush, 1988). The analysis of unexplained variance in student performance must first be partitioned into the school and student level components, if this bias is to be avoided. In previous studies (Young, 1990, 1991a, 1991b, in press; Young & Fraser, 1992a, 1992b), the school effect ranged from 9 to 19 percent of the total unexplained variance in physics achievement, depending upon the age of the student. If not removed from the statistical analysis, this effect could have led to the underestimation of the standard error resulting in the rejection of the null hypothesis. For example, the finding of statistically significant sex differences could be attributable to the underestimation of the standard error. It is imperative, therefore, that the total amount of variance is estimated using a multilevel model approach. This study employed the use of the Hierarchical Linear Model (HLM) developed by Raudenbush (1988) and the computer program, HLM2, developed by Bryk, Raudenbush, Seltzer and Congdon (1989) for these types of analyses.

Because school effects on student performance are multilevel in nature, standard regressions may be misleading, and often underestimate the effects of the school and overestimate student characteristics such as sex differences. The multilevel model consists of a separate between-school regression equation for each b coefficient in the regression model. The Hierarchical Linear Model

(Raudenbush, 1988; Raudenbush & Bryk, 1986) was used in this study to investigate the effect of the classroom environment, instructional quality and time. The multilevel analysis was conducted using science achievement as the student outcome variable, in an attempt to explain these student differences in science achievement.

**Table 1**
***Description of Student Level and School Level Variables***

| | |
|---|---|
| *Outcome Variable:* | |
| Science achievement (science) - NAEP cognitive subtests | |
| Science knowledge (scikn11) | 18-20 items |
| Science uses (scius11) | 17-18 items |
| Science integration (scint11) | 18-19 items |
| *Student Level Variables:* | |
| Sex | Male = 1, Female = 0 |
| Science attitude (attitude) | |
| Interest | 3 item composite |
| Usefulness | 4 item composite |
| Prior science achievement (ability) - NAEP cognitive subtests | |
| Science knowledge (scikn10) | 22 items |
| Science uses (scius10) | 19 items |
| Science integration (scint10) | 22 items |
| Motivation (motiv) - academic motivation | |
| Persistence | sum of 2 items about trying hard at school |
| Instrinsic motivation | sum of 3 items about putting off study |
| Instructional time (time) - material covered | |
| Cuts class now and then | 1 = yes, 0 = no |
| Parent reported homework | hours per week |
| Student reported homework | hours per week |
| Home environment (home) | |
| Parent education | 5 = advanced degree, 1 = high school or less |
| Parent expectations | 5 = advanced degree, 1 = high school or less |
| Duncan socioeconomic index | continuous scale |
| Peer environment (peer) - most of my friends | |
| Plan to go to college | 1 = yes, 0 = no |
| Are really good students | 1 = yes, 0 = no |
| Do well in science | 1 = yes, 0 = no |
| Mass media (media) - out of school reading | |
| Read six or more books | 1 = yes, 0 = no |
| Read a newspaper often | 1 = yes, 0 = no |
| *School Level Variables* | |
| Instructional quality (quality) - teacher reported instructional focus | |
| Lab technique skills | 4 = heavy emphasis, 1 = none |
| Conducting experiments | 4 = greater than weekly, 1 = very rarely |
| Written reports required | 4 = greater than weekly, 1 = very rarely |
| Class environment (class) - teacher reported class attributes | |
| Percent of students to get bachelor's degree | |
| Percent of students to take more science than required | |

Note: All items and scales were standardized before combining into composites

Table 2
*Descriptive Statistics for Student and School Level Variables*

| Variable | N | Mean | Standard Deviation | Minimum | Maximum |
|---|---|---|---|---|---|
| *Student Level* | | | | | |
| Science | 2003 | .00 | .90 | -2.49 | 2.20 |
| Sex | 2003 | .49 | .50 | .00 | 1.00 |
| Attitude | 1850 | .00 | .89 | -2.45 | 2.03 |
| Ability | 1964 | .03 | .88 | -1.68 | 2.64 |
| Motivation | 1981 | .02 | .85 | -3.71 | 1.65 |
| Time | 2001 | .01 | .69 | -1.69 | 2.93 |
| Home | 1988 | .01 | .77 | -2.00 | 1.82 |
| Peer | 2003 | .04 | .73 | -1.23 | .93 |
| Media | 1855 | .02 | .76 | -.83 | 1.24 |
| *School Level* | | | | | |
| Science | 47 | -.02 | .28 | -.69 | .57 |
| Urban | 47 | 2.13 | .77 | 1.00 | 3.00 |
| Ability | 47 | -.01 | .33 | -.78 | .83 |
| Attitude | 47 | .04 | .17 | -.35 | .44 |
| Motivation | 47 | .00 | .23 | -.47 | .85 |
| Time | 47 | -.03 | .19 | -.45 | .53 |
| Home | 47 | -.04 | .28 | -.70 | .79 |
| Peer | 47 | .01 | .18 | -.31 | .64 |
| Media | 47 | .01 | .21 | -.65 | .72 |
| Qual | 47 | .06 | .53 | -1.45 | 1.33 |
| Class | 47 | .05 | .63 | -1.00 | 1.38 |

**Variables used in this Study**

The Longitudinal Study of American Youth included science achievement test items developed by the National Assessment of Educational Progress (NAEP, 1986), and self-reported student background data. In addition, student and teacher surveys and parent interviews provided information on students' attendance, home resources, and exposure to mass media such as television and books. Teachers provided information about the classroom environment and instructional quality. All variables consisted of a combination of items, except for sex of the student. Before combining the items into composite scales, the items were standardized so that they contributed equally towards the combined scale. The years 10 and 11 science achievement measures, *sciknl0*, *sciusl0* and *scintl0* and *sciknl1*, *sciusl1*, and *scintl1*, were previously standardized and then combined into two single scales, *ability* and *science*, respectively. These variables are described in Table 1, and the descriptive statistics provided in Table 2.

**Preliminary Analyses**

The initial stage in HLM analysis involved the estimation of the total variance of the dependent variable, science achievement. The total variance was then further decomposed into between-school and between-student variance as reported in the following sections, in order to determine the source of variations in science achievement. The student level independent variables examined included *sex*, attitude towards science (year 11; *attitude*), prior science achievement (year 10; *ability*), motivation (*motiv*), instructional *time* (class and homework), home environment (*home*), peer characteristics (*peer*) and mass media (*media*). School effects investigated included instructional *quality* (science laboratory emphasis) and *class*room environment. Additionally, student aggregates were also analysed at the school level (level 2) in order to identify any contextual effects. For example, do the effects of the home environment on student achievement vary from school to school or are the effects similar across all schools.

**Table 3**
*Correlation Matrix of School and Student Level Variables*

| | Science | Sex | Attitude | Ability | Motiv | Home | Peer | Media | Time | Quality | Class |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Science | 1.00 | | | | | | | | | | |
| Sex | 0.07* | 1.00 | | | | | | | | | |
| Attitude | 0.24* | 0.17* | 1.00 | | | | | | | | |
| Ability | 0.65* | 0.16* | 0.28* | 1.00 | | | | | | | |
| Motivation | 0.06* | -0.18* | 0.22* | 0.01 | 1.00 | | | | | | |
| Home | 0.33* | 0.00 | 0.18* | 0.37* | 0.11* | 1.00 | | | | | |
| Peer | 0.14* | -0.12* | 0.16* | 0.14* | 0.27* | 0.19* | 1.00 | | | | |
| Media | 0.18* | -0.03 | 0.14* | 0.18* | 0.11* | 0.12* | 0.16* | 1.00 | | | |
| Time | 0.19* | -0.17* | 0.15* | 0.18* | 0.42* | 0.23* | 0.27* | 0.10* | 1.00 | | |
| Quality | 0.13* | 0.00 | 0.05 | 0.14* | -0.02 | 0.22* | 0.10* | 0.02 | 0.09* | 1.00 | |
| Class | 0.28* | -0.03 | 0.11* | 0.36* | 0.10* | 0.36* | 0.21* | 0.12* | 0.17* | 0.34* | 1.00 |

* Statistically significant at $p = 0.01$

For each of the indicators, there were between 1855 and 2003 students and 47 schools available for analysis. The general descriptive statistics are provided in Table 2, with a correlation matrix given in Table 3. Although all of the indicators correlated with science achievement at a statistically significant level, some had a stronger relationship than others. In particular, prior science achievement, attitude towards science, home and classroom environment were much stronger than sex and quality of instruction.

When initial hierarchical linear model analyses were run on science achievement, the within schools variance was 0.81, while the between schools variance was 0.046 (Table 4). This means that most of the variance (95%) was at the student level. When seven student level variables were included in the model, there was a major reduction in both between schools and within schools variability. These seven effects accounted for 37 percent of the unexplained student level variance and 75 percent of the school level differences. School effects were then modeled and found to further reduce the school level variability by 11 percent in the final explanatory model.

Table 4
*Variance Components Analysis*

| Effect | Within School Variance | Between School Variance |
|---|---|---|
| No independent Variables | .8105 | .04554 |
| 8 Student Variables (Level 1) | .5070 (37.4%) | .01134 (75%) |
| 8 Student & 10 School Variables (Levels 1 &.2) | .5068 | .00779 (82.9%) |
| 5 Student & 2 School Variables (Levels 1 & 2) | .5073 | .00638 (86.0%) |

## The Hierarchical Linear Model

The HLM2 computer package (Bryk, Raudenbush, Seltzer & Congdon, 1989) was used to analyse a random hierarchical linear model initially with no other predictors. The average science achievement was specified for the Level-1 and Level-2 models:

$$Science_{ij} = \beta_{0j} + r_{ij} \qquad \text{Equation 1}$$

$$\beta_{0j} = \gamma_{00} + u_{0j} \qquad \text{Equation 2}$$

where $Science_{ij}$ represents the dependent variable, science achievement for student i in school j, $\beta_{0j}$ represents the intercept or mean science achievement for all students in j schools and $r_{ij}$ represents the Level-1 error term normally distributed with a mean of zero and a variance of $\sigma^2$, $\gamma_{00}$ represents the grand mean of science achievement for students with $u_{0j}$ the random effect associated with school j (set at a mean of zero and a variance of $\tau_{00}$).

When the variance components model was analysed, the total variance was 0.8560 with $\sigma^2$ being 0.8105 (95%) and $\tau_{00}$ being 0.04554 (5%) as described in Table 4. That is, 95 percent of the overall unexplained variance was at the student level, while 5 percent of the variance was at the school level. The variance components model consists of the criterion variable only, with no independent or predictor variables. Once the variance components for student and school levels were established, further exploratory analyses were run in order to determine the efficacy of the explanatory model.

When student level predictors were included in the model, there was a reduction in $\sigma^2$ from 0.8105 to 0.5070 (a 37.4 percent reduction). The predictors were sex of the student, attitude towards science, prior science achievement (ability), motivation of the student, instructional time, home environment, peer characteristics and mass media (see equation 3). All of these predictors were statistically significant, with the exception of sex, motivation and peer environment (see Table 5). The weak and insignificant sex slope ($\beta_{1j}$ = -0.06, t = -1.73) indicated that, while sex correlated slightly with science achievement in a positive direction (that is, boys outperformed girls in science achievement), there was a significant reduction in this effect once other student variables were accounted for leaving a negative slope (that is, girls appeared to outperform boys). In other words, the sex differences in science achievement were accounted for, by student characteristics such as attitude towards science and prior ability. These two slopes were statistically significant in explaining the within school variance, with attitude towards science having a weaker, positive effect ($\beta_{2j}$ = 0.05, t = 2.39) than prior science ability ($\beta_{3j}$ = 0.53, t = 26.19). The strong, positive prior science ability slope was the most significant student level predictor. Similarly, instructional time (reflecting number of missed classes and hours spent doing homework), home environment and mass media were significant in explaining science achievement ($\beta_{5j}$ = 0.11, t = 4.00; $\beta_{6j}$ = 0.09, t = 3.73; and $\beta_{8j}$ = 0.08, t = 3.20 respectively), although weaker. Student motivation ($\beta_{4j}$ = 0.00, t = 0.18) and peer environment ($\beta_{7j}$ = 0.02, t = 0.74) did not appear to contribute significantly towards explaining student differences in science achievement. These variables were later removed from the final explanatory model of science achievement.

**Table 5**
***Hierarchical Linear Model results for Science Achievement: Student Level Variables Model***

| Effect | Coefficient | t-ratio |
|---|---|---|
| Student Level Intercept | -0.02 | -0.81 |
| Sex | -0.06 | -1.73 |
| Attitude | 0.05 | 2.39* |
| Ability | 0.53 | 26.19* |
| Motivation | 0.00 | 0.18 |
| Time | 0.11 | 4.00* |
| Home | 0.09 | 3.73* |
| Peer | 0.02 | 0.74 |
| Media | 0.08 | 3.20* |

Note: * statistically significant at p = 0.05
sigma squared = 0.5070 (within school variance) and tau = 0.01134 (between school variance)

Of the ten school level characteristics and aggregates examined in this model (equation 3 and 4) only the student aggregate ability and class environment were statistically significant (see Table 6). The student aggregate ability had a strong, positive effect ($\gamma_{02}$ = 0.24, t = 2.11) indicating that the combined peer ability was associated with individual student performance. However, the class environment, that is the degree to which students aspire to tertiary education and science education, appeared to have a negative effect upon individual science achievement ($\gamma_{09}$ = -0.14 t = -3.09). These school effects were left in the final explanatory model, namely, average science achievement in year 10 (*ability*) and classroom environment (*class*). These school effects accounted for 10 percent of the between school variance, with the student effects explaining about 75 percent of the same variance.

$$\begin{aligned}\text{Science}_{ij} = \beta_{0j} + \beta_{1j}\text{Sex}_{ij} + \beta_{2j}\text{Attitude}_{ij} + \beta_{3j}\text{Ability}_{ij} + \beta_{4j}\text{Motivation}_{ij} \\ + \beta_{5j}\text{Time}_{ij} + \beta_{6j}\text{Home}_{ij} + \beta_{7j}\text{Peer}_{ij} + \beta_{8j}\text{Media}_{ij} + r_{ij}\end{aligned}$$ Equation 3

$$\begin{aligned}\beta_{0j} = \gamma_{00} + \gamma_{01}\text{Urban}_j + \gamma_{02}\text{Ability}_j + \gamma_{03}\text{Attitude}_j + \gamma_{04}\text{Motivation}_j \\ + \gamma_{05}\text{Home}_j + \gamma_{06}\text{Peer}_j + \gamma_{07}\text{Media}_j + \gamma_{08}\text{Time}_j + \gamma_{09}\text{Class}_j \\ + \gamma_{10}\text{Quality} + u_{0j}\end{aligned}$$ Equation 4

Table 6
*Hierarchical Linear Model results for Science Achievement: Initial Explanatory Model*

| Effect | Coefficient | t-ratio |
|---|---|---|
| Student Level Intercept | 0.00 | 0.04 |
| *School Level Variables* | | |
| Urban | -0.01 | -0.23 |
| Ability | 0.24 | 2.11* |
| Attitude | -0.11 | -0.69 |
| Motivation | -0.00 | -0.04 |
| Home | 0.08 | 0.64 |
| Peer | -0.00 | -0.01 |
| Media | -0.06 | -0.44 |
| Time | -0.25 | -1.49 |
| Class | -0.14 | -3.09* |
| Quality | 0.06 | 1.09 |
| *Student Level Variables* | | |
| Sex | -0.06 | -1.65 |
| Attitude | 0.05 | 2.51* |
| Ability | 0.52 | 25.18* |
| Motivation | 0.01 | 0.33 |
| Time | 0.11 | 4.17* |
| Home | 0.09 | 3.67* |
| Peer | 0.02 | 0.81 |
| Media | 0.07 | 3.02* |

Note: * statistically significant at p = 0.05
sigma squared = 0.5068 (within school variance) and tau = 0.00779 (between school variance)

The final explanatory model is described in Table 7, with 2 school level variables and 5 student level variables (see equations 5 and 6). At the school level, the student ability aggregate effect was positive, while the class environment effect was negative. At the student level, the positive, student effects were attitude, prior ability, instructional time, home environment, and mass media.

$$\text{Science}_{ij} = \beta_{0j} + \beta_{1j}\text{Attitude}_{ij} + \beta_{2j}\text{Ability}_{ij} + \beta_{3j}\text{Time}_{ij} + \beta_{4j}\text{Home}_{ij} + \beta_{5j}\text{Media}_{ij} + r_{ij} \qquad \text{Equation 5}$$

$$\beta_{0j} = \gamma_{00} + \gamma_{01}\text{Ability}_j + \gamma_{02}\text{Class}_j + u_{0j} \qquad \text{Equation 6}$$

Table 7
*Hierarchical Linear Model results for Science Achievement: Final Explanatory Model*

| Effect | Coefficient | t-ratio |
|---|---|---|
| Student Level Intercept | 0.01 | -0.58 |
| *School Level Variables* | | |
| Ability | 0.19 | 2.35* |
| Class | -0.13 | -3.21* |
| *Student Level Variables* | | |
| Attitude | 0.05 | 2.32* |
| Ability | 0.52 | 25.55* |
| Time | 0.12 | 4.90* |
| Home | 0.10 | 4.14* |
| Media | 0.08 | 3.25* |

Note: * statistically significant at p = 0.05
sigma squared = 0.5073 (within school variance) and tau = 0.00638 (between school variance)

## Discussion

The significance of the relationship between student performance in science achievement and factors such as the student's home and school environment was confirmed in this HLM analysis, with most of the student characteristics tested found to contribute towards explaining student differences in science achievement. In particular, these analyses revealed the importance of including prior achievement in science as an essential part of the explanatory model. Other student level characteristics which formed a fundamental part of this model were the attitude of the student towards science, student instructional time, home environment and the effect of mass media on the student. At the school level, the average prior student science achievement and classroom environment were the most significant effects, with quality of instruction having a weak effect.

## Conclusions

The present analyses suggest that educational productivity is largely driven by individual-level psychological factors. Most of the variance accounted for is at the individual-level rather than school-level. At the individual-level, moreover, the correlations are in the theoretically expected direction, as are all significant regression coefficients. These results correspond to those based on structural modeling of the productivity model (Reynolds & Walberg, 1991, 1992).

As estimated in the present data, therefore, science achievement depends much more on the characteristics of individual students than on the schools they attend. Indeed, as many studies show, subsequent achievement is preponderantly a function of previous achievement, as indicated by the .65 pretest-posttest correlation and the correspond-ingly highly significant regression weight.

The importance of the environmental variables, nonetheless, should not be underestimated. Previous achievement may be preponderant because it represents the accumulation of learning over many previous school years - nine in the present sample. The environmental factors are measured only for the current year. Therefore, their moderate correlations and general statistical significance can be taken as signs of hope that if they were to be improved over several years, considerable learning gains would ensue.

Of course, the results of this study do not rule out the possibility of contextual effects in science achievement. Because behavior is affected by the family, school, and community contexts in which it occurs (Bronfenbrenner, 1979), effects on science achievement and literacy may be more subtle and complicated than measured in this study. Process of models educational productivity verify such direct, indirect, and mediated influences. Moreover, effects may be reciprocal or may depend on particular constellations of family, school, and individual factors.

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